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NONPARE, A CONSULTATION SYSTEM FOR ANALYSIS OF DATA

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DECEMBER 1988

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Nonpare, a consultation system for analysis of data using nonparametric statistical procedures, is under active development. It is intended to serve as an intelligent interface that will act as a guide, an instructor, and an interpreter to a body of statistical software. Nonpare exists as a prototype, with a limited release planned in 1989 for field testing. Keywords:

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1. Introduction

Statistical software packages, to large extent, accept any properly configured data set and proceed to process it. Few if any checks are made to ensure the adequacy of the data and the suitability of the analysis, and little is done to provide an explanation or interpretation of the results. This requires a great deal from the user. Declining computation costs, together with increased availability of computers and proliferation of statistical software, has further enhanced the opportunity for faulty data analysis. Application of expert system techniques from artificial intelligence to produce more cognizant software is one approach to reversing this unfortunate trend.

In 1985, a workshop sponsored by AT&T Bell Laboratories brought together many of the active investigators in artificial intelligence and statistics and was the genesis of a book by the same title edited by Gale [1]. This reference is in essence the proceedings of the workshop; but the papers given there, some with extensive bibliographies, provide the most complete centrally-located account of research in this topic to date.

This report details an effort underway at the US Army Ballistic Research Laboratory (BRL) to develop a consultation system for analysis of data using nonparametric statistical procedures. The system, called Nonpare, is intended to serve as an intelligent interface that will act as a guide, an instructor, and an interpreter to a body of statistical software. The system is currently a prototype, with a first release planned for 1989 for field testing.

2. Nonpare

Nonparametric statistics is too large an area to hope to encompass at once, especially if the entire field of mathematical statistics is partitioned into parametric and nonparametric procedures. The common-sense approach to construction of consultation systems suggests limiting the domain of application, but nonparametric statistics has qualities that make it strongly appealing.

Nonparametric data analysis is characterized chiefly by the absence of restrictive distribution assumptions – notably freedom from dependence on the normal (Gaussian) distribution. Many nonparametric statistical procedures are exact rather than approximate for small data sets, and they are the only confirmatory procedures which can be used to analyze data collected on a nominal or an ordinal scale of measurement. For these and other compelling reasons advanced, for example, by Conover, [2] Hollander and Wolfe, [3] and Lehmann, [4] nonparametric procedures find use in a wide variety of disciplines.

2.1 The System Structure

Nonpare uses Genie, an expert system shell developed at the BRL, [5] to provide a frame-based production system with forward and backward inferencing as well as an explanation facility that allows the user to interrogate the system – what hypotheses are being entertained, what rules are being verified, what facts are in evidence. Genie was chosen over commercial expert system shells for the research and development of Nonpare because of its accessibility for modification.

Nonpare, shown schematically in figure 1, consists of three subsystems in addition to Genie.

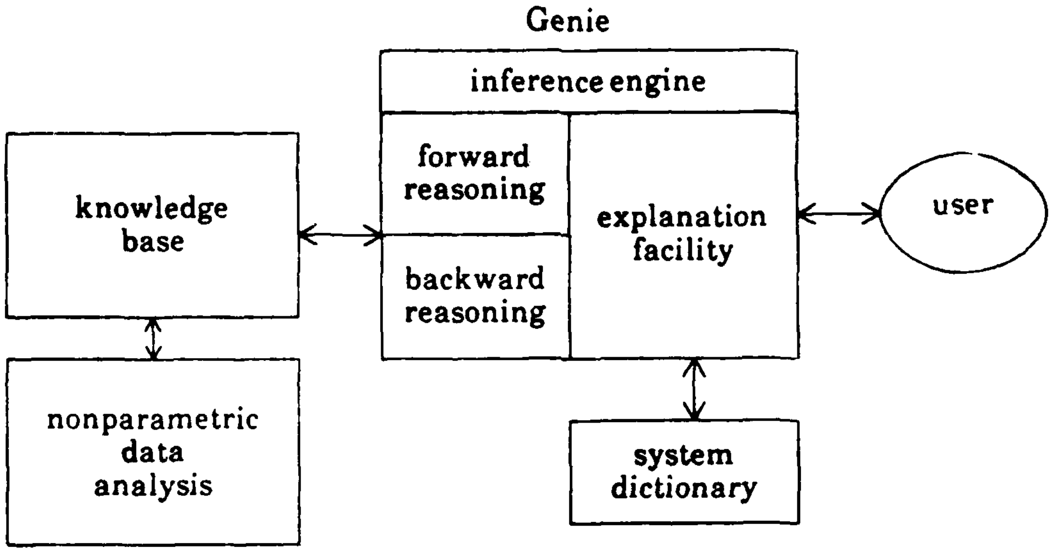

Figure 1. Nonpare system overview.

The system dictionary is a facility whose purpose is to provide on-line explanation of statistical jargon that may appear during the interactive dialog between Nonpare and the user. Expert domain knowledge, codified in English-like rules, resides in the knowledge base. Once an appropriate procedure(s) has been identified, the data are analyzed and the results explained by the nonparametric data analysis component. Graphics is used to summarize the data and enhance the explanation. In total, the user is led within system limitations to an appropriate statistical procedure through an interactive process in which the user is questioned and can in turn question the consultation system. Nonpare is written in Interlisp-D and currently runs on Xerox 1100 Series Lisp machines.

3. An Illustrative Session

Following the dictum of American educator John Dewey (1859-1952) that "We learn by doing," a detailed session with Nonpare follows, in which the main system features are illustrated.

Example 3.1

Suppose that a ballistician needs to assess the effectiveness of a newly designed kinetic energy penetrator against a specific armor plate. In particular, the experimenter would like to establish whether the probability of perforation exceeds .80, a level already attained with existing technology. Fourteen rounds are fired, and [p]erforation and [n]onperforation recorded to obtain: n, p, p, p, n, p, p, p, p, n, p, p, p, p. Is the Pr{perforation} > .80 ?

(A diversion here. Searching for a statistical procedure with a set of data already collected is precisely how *not* to proceed. The purpose for collecting the data should first be established, and then the statistical tools available to support this purpose determined. Then the collection and analysis of data can proceed in an informed manner. Lamentably, the methodology-search scenario is enacted over and over again; so this example is not too contrived.)

It should be apparent from the onset that the question regarding Pr{perforation} > .80 can never be answered unequivocally yes or no, but only with some degree of qualification.

Nonpare presently has nineteen distinct data analysis procedures at its disposal; the number continues to increase. No assumptions have been made about their frequency of use; one procedure has not been declared most likely to be exercised, a second procedure next most likely, and so on, since the base of potential users is so broad. For the user, this means that any procedure is a likely starting point, as in this session, the dialog of which begins in figure 2. In the remainder of this section, the conventions that boldface denotes system prompts and brackets contain user input will be adopted. An occasional system response may be italicized but should not be confusing within the context of its appearance.

```
Do you have a sample X1, ..., Xn? y
Are you interested in whether the data conform to a specified
distribution? n
Are you interested in the probability of occurrence of a particular
category or event? y
Enter the name of the category of interest -> perforation
Are the n trials producing the values X1, ..., Xn independent? ^
```

Figure 2. Beginning dialog with Nonpare.

The session begins with a question about the configuration of the data.

Do you have a sample $X_1, ..., X_n$? The data, *n*, ..., p, look like $X_1, ..., X_n$; respond [y]es.

Are you interested in whether the data conform to a specified distribution ? Nonpare is investigating a possible goodness-of-fit situation. A statistician, anticipating an approach to this problem, might find a [y]es response is appropriate here. A nonstatistician, for whom this portion of the system is designed, and who is interested in whether Pr{perforation} > .80, should respond [n]o, as indicated.

Are you interested in the probability of occurrence of a particular category or event ? [y]es. The user is interested in the probability of occurrence of a perforation.

Enter the name of the category of interest. [perforation]. Domain-dependent terminology is being introduced.

Are the n trials producing the values X_1, ..., X_n independent ? Suppose the user is unsure of the technical implications of the term "independent." An acceptable response is [What is independent] – as shown in figure 3.

```
Are the n trials producing the values X1, ..., Xn independent? what is in
dependent

Independence relates to freedom from external influence or control- here,
 the reference is to measurements (data) being free to assume values
without regard to other measurements that may be made.

Are the n trials producing the values X1, ..., Xn independent? y
Does each trial have the same probability p of producing the perforation
? y
Are you interested in considering whether the probability of occurrence
of the perforation equals or is bounded by some specified value p*? ^
```

Figure 3. A call to the system dictionary.

Independence relates to freedom from external influence or control – here, the reference is to measurements (data) being free to assume values without regard to other measurements that may be made.

This illustrates a dilemma for the subject area specialist. It may be impossible to rigorously define a term without reliance upon other terms that are equally obscure to a user with only a modest statistical background. This is the case here, where independence is bound to basic concepts of probability theory. Nonpare's response conveys the notion, but regrettably not the substance, of independence. More work is needed here. For now, assume the experimenter has collected a set of independent data.

Are the n trials producing the values X_1, ..., X_n independent ? [y]es.

Does each trial have the same probability p of producing the perforation ? [y]es. Notice that Nonpare is now using language the user provided, when it talks about probability of perforation.

Are you interested in considering whether the probability of occurrence of the perforation equals or is bounded by some specified value p* ? [y]es. The user is interested in the inequality Pr{perforation} > .80. After a [y]es response, the system suggests a possible approach, shown in figure 4.

The binomial test is an appropriate procedure. To execute the binomial test, use the menu to complete this statement:

I am interested in testing the null hypothesis that: *The probability of occurrence of the perforation*

Pick One

equals some value p*
does not exceed p*
is at least p*

Figure 4. A call to the nonparametric data analysis subsystem.

The menu allows the user to select either a two-sided or one-sided test of hypothesis and is a potential source of error. Beginning statistics students, not realizing that a null (or empty) hypothesis is chosen to be rejected, might mistakenly choose **is at least p*** at this juncture. Here again, *some* level of statistical competence is required. Selecting the hypothesis **does not exceed p*** from the menu using a mouse, the user obtains for confirmation (figure 5) the statement:

I am interested in testing the null hypothesis that: ***The probability of occurrence of the perforation does not exceed p*.***

I am interested in testing the null hypothesis that: *The probability of occurrence of the perforation* does not exceed p*

Specify the sample size n -> 14

Specify a value for p* -> .80

Specify the number of datum values assigned to the perforation -> 11

Figure 5. Hypothesis confirmation and input parameter declaration.

Specify the sample size n. [14]

Specify a value for p*. [.80]

Specify the number of datum values assigned to the perforation. [11]

The first two "Specify ... " commands determine the appropriate binomial distribution; the third determines the size of the critical region for the statistical procedure, which is explained in figure 7, following the system-generated histogram shown in figure 6.

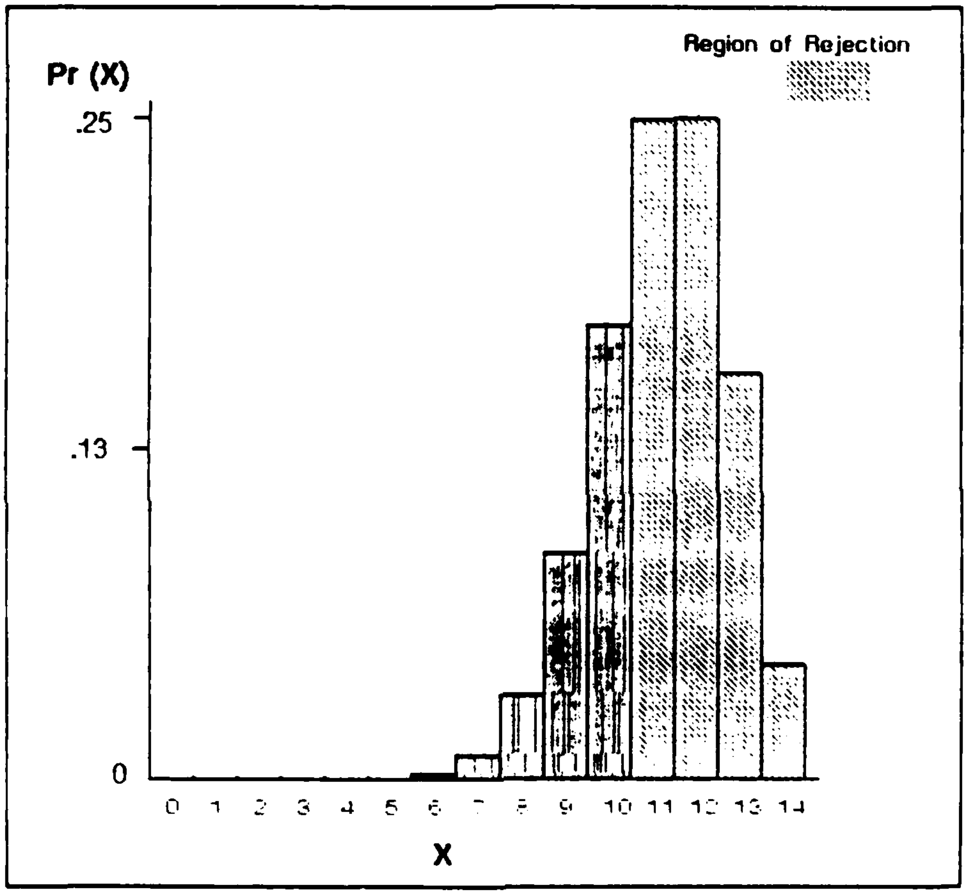

Figure 6. Statistical graph summary.

The histogram displays the probability of observing exactly n (n=0, ..., 14) armor perforations in fourteen shots if the true (but unknown) Pr{perforation} = .80. A statistician will readily assimilate this graph. If the user merely looks at it as a plot involving n rounds in which the light gray region, corresponding to $n \geq 11$, holds some special significance, and it provides some reassurance regarding the unseen computations, it will have served its purpose here. Figure 7, which appears on the terminal simultaneously, explains that

The critical level of this test, corresponding to the light gray region, is .69

This means that if you reject the hypothesis (*The probability of occurrence of the perforation does not exceed .8*) **you do so with a .69 probability of being in error.**

> The critical level of this test, corresponding to the light gray region, is .69
>
> This means that if you reject the hypothesis (*The probability of occurrence of the perforation does not exceed .8*) you do so with a .69 probability of being in error.
>
> Would you like to run the binomial procedure again? n

Figure 7. Explanation and interpretation of results.

Since the investigation began with the assumption (null hypothesis) that the Pr{perforation} $\leq$ .80, the evidence collected – eleven perforations, three nonperforations – is not sufficient to support abandonment of that assumption. A probability of being in error of .69 is more than a reasonable person would be willing to assume. And so, the response to the original question, Is the Pr{perforation} > .80 ? is a qualified no, the qualification being expressed through invocation of the critical level.

Would you like to run the binomial procedure again ?

At this juncture, an experimenter might well be asking a number of "What if ..." questions. "What if I had been able to afford three more firings?" or, "What if I had observed one more perforation?" and so on. A response of [y]es here allows the user to exercise the binomial procedure directly, without having to respond again to all the preliminary questions. A [n]o response is given, but this is an excellent place to use Nonparc's tutorial capabilities to study the sensitivity of the binomial procedure to modification of parameter values or slight changes in the data.

Are you interested in determining an interval in which the probability p of occurrence of the perforation lies?

The foregoing analysis suggests that an assertion that the probability of perforation lies in the interval (.80, 1] cannot be made. What interval might be expected to capture this unknown parameter? A response of [y]es causes this question to be answered, first graphically, as in figure 8, and then verbally, as in figure 9.

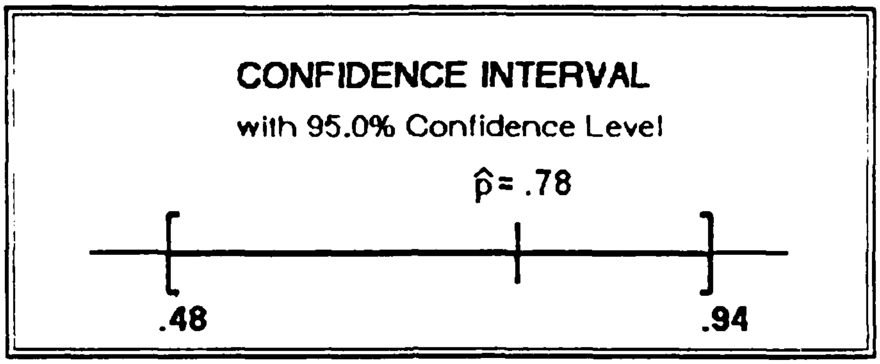

Figure 8. Display for a 95% confidence interval.

Figure 8 shows that the Pr{perforation}, whose estimate based on the fourteen firings is $\hat{p}$ = .78, lies within the interval [.48, .94] with a high level of confidence. This interval is so broad one can see why the assertion that Pr{perforation} > .80 is ill-advised. The formal interpretation of the confidence interval is given as

The probability of occurrence of the perforation is contained in the interval [.48, .94] with an a priori probability .95 .

```
Are you interested in determining an interval in which the probability p
of occurrence of the perforation lies? y

The probability of occurrence of the perforation is contained in the
interval [.48,.94] with an a priori probability .95.

Would you like a confidence level other than .95 ? n
```

Figure 9. Explanation and interpretation of the confidence interval.

Would you like a confidence level other than .95 ? [no]. The 95% confidence level was prechosen. A [y]es response allows the user to control the confidence level. The session is terminated with a [n]o response, shown in figure 9.

At the conclusion of the session the inference engine displays a fact solution tree for all the intermediate decisions leading to the final conclusion. Buttoning with a mouse any node of the fact tree produces the logic leading to that location. In figure 10, fact11 was buttoned, and the corresponding trace is displayed beneath the fact tree. These are features of the inference engine rather than Nonpare, but they are valuable as diagnostics to the developer and provide some measure of reassurance to the user.

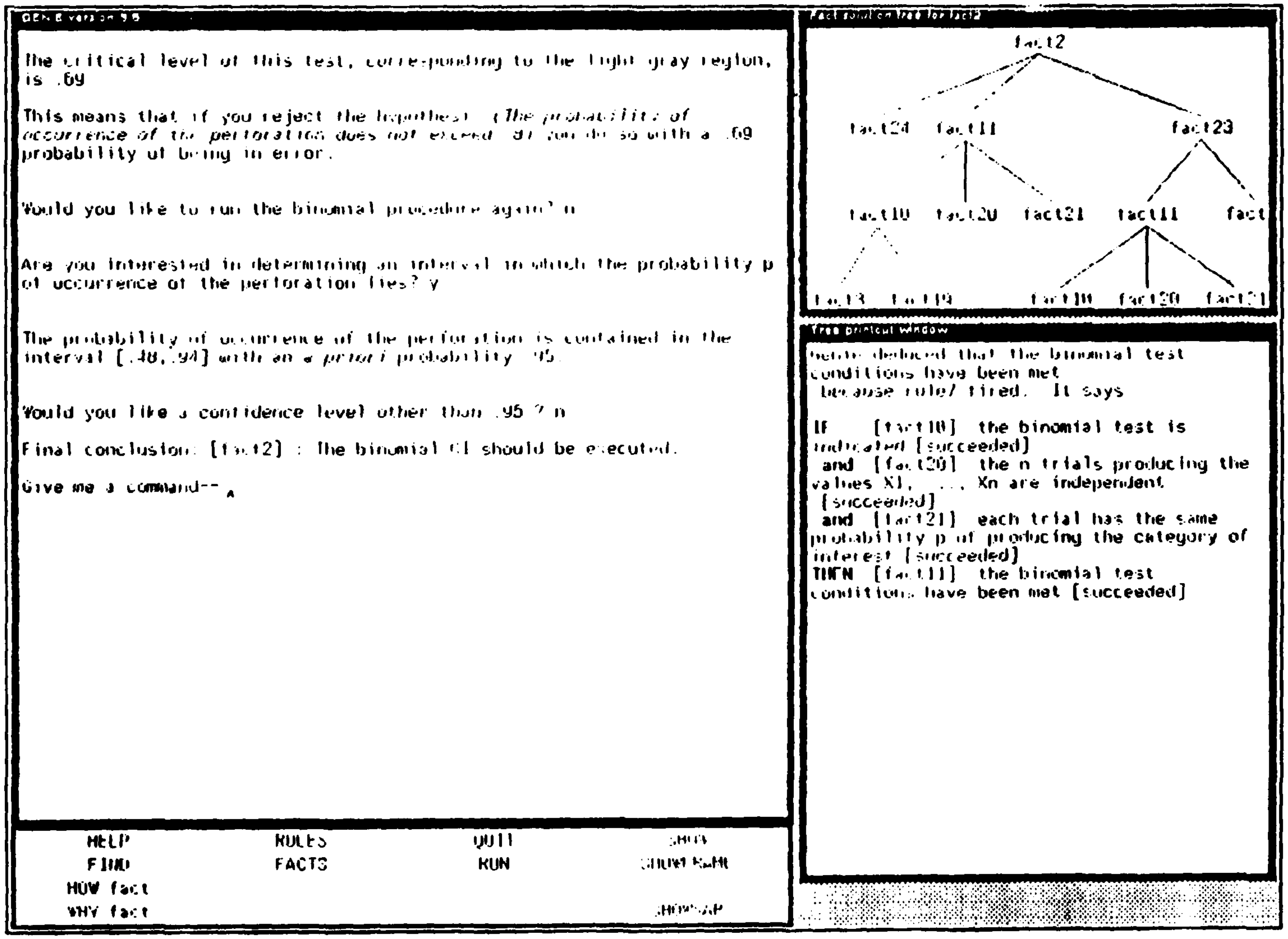

Figure 10. Session conclusion

4. Conclusions

Nonpare, a consultation system for analysis of data using nonparametric statistical procedures, has been described; and most of its operational features have been illustrated. The essence of the system is the rule-based interface with accompanying software for data analysis and the interpretation of the ensuing computations. Nonpare is under active development, but its feasibility as an operational system has been established. Enlargement of the rule-base and the addition of more statistical procedures is clearly indicated before it can approach its potential. Not surprisingly, tangential problems in basic research have been spawned by this effort. A first release is planned for 1989 for field testing.

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[3] M. Hollander and D.A. Wolfe, *Nonparametric Statistical Methods* (John Wiley, 1973).

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[5] F.S. Brundick, et.al.,Genie: An inference engine with applications to vulnerability analysis, Technical Report BRL-TR-2739, US Army Ballistic Research Laboratory, Aberdeen Proving Ground, MD (1986).

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